REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
21 November 1996

3. REPORT TYPE AND DATES COVERED
Final Report; 1 Feb 90—31 May 96

4. TITLE AND SUBTITLE
Evolution of porosity and seismic properties of shallow oceanic crust

5. FUNDING NUMBERS
G:
N00014-90-J-1625

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research, code 322GG
800 North Quincy Street
Arlington, VA 22217-5000

10. SPONSORING / MONITORING

19961216 040

11. SUPPLEMENTARY NOTES
This is the Final Technical Report of research performed under an ONR grant

12a. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The uppermost oceanic crust undergoes substantial changes in physical properties as it is transported away from a mid-ocean ridge. Porosity must play a central role in dictating such changes. This study sought to use seismic measurements to infer porosities and so to gain an understanding of crustal aging. Techniques used were development of the theory linking porosity to seismic velocity, microscope investigation of seafloor lavas, measurement of ultrasonic velocities in the laboratory, comparisons of theory with field measurements of seismic velocity, and field investigations of seafloor extrusives exposed on land. The project demonstrated that seismic velocities in the seafloor are strongly dependent on pore shape. Those velocities, and the nature of their increases with age and depth, were shown to be completely consistent with the concept of progressive sealing of cracks by alteration products. The project also showed how seismic measurements can be interpreted in terms of overall porosity and the distribution of that porosity over different pore shapes. Together with other ONR-supported crustal aging studies, the project confirmed the idea that the evolution of the oceanic crust is governed by its circulating fluids, making permeability, and hence porosity, key factors in controlling the state of the crust.

14. SUBJECT TERMS
Porosity; Seismic properties; Crustal evolution

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Final Technical Report
ONR Grant N00014-90-J-1625

EVOLUTION OF POROSITY AND SEISMIC PROPERTIES OF SHALLOW OCEANIC CRUST

Period of Performance: February 1, 1990 — May 31, 1996

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Long Term Goals

The upper few hundred meters of the ocean crust undergoes substantial changes in physical properties as the crust is transported away from the mid-ocean ridge at which it was formed. Observed increases in seismic velocity, both with age and with depth, have been attributed to reductions in porosity associated with seawater-rock interactions. Our goal, indeed the goal of all investigators involved in the ONR-supported crustal aging studies, has been to understand these changes.

Project Objectives

The specific goal of the project was to relate the changes in seismic velocity with depth and age in the seafloor to the porosity structure at all scales.

Background

This study began in 1990 at a time when seismic investigations of the structure of the uppermost igneous crust of the seafloor seemed, from a traditional rock physics perspective, to suggest massive and rapid reductions in porosity with age. The key seismic observation was a doubling of compressional-wave velocities in layer 2A in a mere ten million years at one site in the Atlantic, with the suggestion from rather equivocal measurements that similar rapid increases exist in almost all young crust. This project was born with the suggestion that in crust subjected to alteration and hydrothermal mineralization, thin cracks formed on extrusion of lava into sea water can be expected to seal early, giving the crust a very large increase in seismic velocity with age.

Approach

When this project began, the few rock physics theories which consider pore shape could not be applied to the seafloor problem, because seafloor extrusives have a much higher crack density than the theories could handle. Our first task was to extend the theories so that they could be applied to seafloor conditions, then to use these theories to develop inversion procedures so that the porosity structure could be inferred from seismic or ultrasonic measurements.

Seismic properties are influenced by porosity at all scales, from microscopic to outcrop scale, so it was necessary to investigate porosity at all scales. Seafloor samples were examined by scanning electron microscope and sent to collaborators N.I. Christensen (Purdue), G.J. Iturrino (then at Miami), and M.H. Salisbury (Bedford) to measure ultrasonic properties under pressure. From the pressure dependence the porosity structure could be inferred. The results were compared with results from downhole logging and marine seismic experiments. To understand the nature of the porosity, seafloor extrusives were mapped at the oucrop scale at the Troodos Ophiolite, Cyprus, so that the distribution

of porosity over cracks, vesicles, pillow selvages, and inter-pillow voids could be determined. The Troodos analysis was used as a guide in interpretating seismic data from the East Pacific Rise.

Accomplishments and results

- Extension of rock physics theories to very high porosities [*Berge et al.*, 1992]. Implementation of inverse techniques to compute porosities and aspect ratios from ultrasonic velocity measurements at different confining pressures and development of inversion techniques to impose constraints on porosities and aspect ratios from field seismic measurements [*Berge et al.*, 1992; *Johnston et al.*, 1995; *Ludwig et al.*, 1996a].
- Porosity determinations from laboratory measurements of velocity in rock samples from young ocean floor. Qualitative verification of the porosity determinations from scanning electron microscopy [*Johnston, et al.*, 1995; *Ludwig, et al.*, 1996b; *Wilkens & Salisbury*, 1996].
- Porosity determination in 0–100,000-yr-old crust at the East Pacific Rise from seismic measurements [*Ludwig et al.*, 1996a].
- Analysis of porosity in the extrusives of the Troodos Ophiolite and comparison with the East Pacific Rise [*Ludwig et al.*, 1993, *Ludwig et al.*, 1996a, *Karsten et al.*, in prep.].
- The discovery that in bringing up low-porosity rocks from the seafloor the pressure release may cause the rocks spontaneously to rupture [*Johnston et al.*, 1995].
- The demonstration that the observed age and depth dependence of seismic velocities in seafloor extrusives is completely consistent with progressive crack sealing with only minor reduction in porosity [*Wilkens et al.*, 1991; *Fryer et al.*, 1991; *Fryer et al.*, in prep.]
- Confirmation that the layer 2A/2B boundary is not a mere porosity change but is instead a transition from extrusives to sheeted dikes [*Ludwig et al.*, 1996a].

Scientific impact and transitions

In 1990 the rapid increase of seismic velocities with depth and age in the seafloor was still an enigma and the nature of the layer 2A/2B boundary was mostly conjecture. Largely because of this project, it is now widely accepted that a small degree of alteration producing a very modest reduction in porosity can dramatically increase seismic velocities. Through this and other ONR-supported studies of crustal evolution, the mechanisms and consequences of such porosity modification are now being explored and our understanding of the processes of seafloor evolution advanced. The layer 2A/2B boundary, in the East Pacific at least, is now confirmed as the boundary between porous extrusives and significantly less porous material, probably dikes. The 2A/2B boundary is clearly not just a porosity front controlled by progressive crack sealing.

Custal evolution studies have undergone a transition. The various studies ONR-supported studies, including this one, have advanced as far as possible without substantially more samples and downhole data from seafloor holes spanning a range of ages. The general area of crustal evolution studies is a vibrant area of research, but the primary focus now is the Ocean Drilling Program.

Refereed publications supported or partially supported by this project

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Graduate Students supported by this project:

Patricia Berge (Ph.D., 1991)
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Patrick Johnke (left graduate school, 1994)
Charles Kerton (M.S., 1996)
Noel Ludwig (M.S., 1993)
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